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A four-year experience with the graduate curriculum for Systems Engineering at UTEP and its convergence/divergence with GRCSE

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A four-year experience with the graduate curriculum for Systems Engineering at UTEP and its correspondence with the Graduate Reference Curriculum for Systems Engineering (GRCSE)

Abstract

The professional Master of Science in Systems Engineering (MSSE) program at UTEP was approved in 2009, before the development of the Graduate Reference Curriculum for System Engineering (GRCSE) v0.25 released in December 2010. GRCSE v1.0 (released December 2012) is part of the Body of Knowledge and Curriculum to Advance Systems Engineering (BKCASE) project of the Systems Engineering Research Center (SERC). GRCSE is a set of recommendations, from invited experts from industry, government, academia, and various professional organizations, for a systems-centric masters' level graduate program in system engineering, together with implementation guidance for a university to satisfy the suggested requirements. GRCSE includes recommendations for a program architecture and core body of knowledge, as well as for objectives, student outcomes, and assessment methodologies.

This paper investigates the correspondence between the MSSE Program and the GRCSE in terms of curricula, architecture, and core body of knowledge, including features which were deemed crucial for the success of this particular program application. The paper also reports MSSE Program outcomes and objectives attainment, as well as achievements during the first four years of the program. Based on alumni and employer feedback, enhancements that will increase MSSE Program alignment with the GRCSE are possible, and are discussed. Finally, the paper presents insights from the authors' experience with the MSSE which may inform the further development of GRCSE.

Keywords: Systems Engineering, Education, Curriculum, GRCSE, SERC

INTRODUCTION

Our local M.S. in Systems Engineering Program was established to meet local needs for Science, Technology, Engineering and Math (STEM) and economic development, as well as national needs for system engineering education. From the beginning, the need to properly develop a full systems engineering curriculum was apparent. At the same time, there was a growing awareness that systems engineering programs nationally and internationally would at some point begin to coalesce toward a uniformly demanded and standardized core curriculum. A reference curriculum was soon provided by the GRCSE.

The needs of the U.S. are embodied by the following quotation. The Deputy Assistant Secretary of the Air Force for Science, Technology and Engineering commissioned the National Research Council of the National Academies to examine the role that Systems Engineering can play during the defense acquisition life cycle and address the root cause of program failure during the early phase of the program. In some of its findings, the National Research council states:

> "*There is a need for an appropriate level of **SE talent** and leadership early in the program, with clear lines of accountability and authority. Senior **SE personnel** should be experienced in the product(s) domain, with strong skills in architecture development, requirements management, analysis, modeling and simulation, affordability analysis, and specialty engineering disciplines (e.g., reliability, maintainability, survivability, system security, and technology maturity management*" [AFSB, 2008].

GRCSE: Graduate Reference Curriculum for Systems Engineering

GRCSE "is a set of recommendations for the development and implementation of a systems-centric (Fabrycky 2010) master's level graduate program in systems engineering (SE). … GRCSE is designed for worldwide use. As such, it respects and accommodates the tremendous diversity in the markets that universities serve, the educational systems under which those universities operate, the variation in size of student body and faculty, accreditation programs, and other factors that affect program content and delivery. Therefore, GRCSE provides a broad set of recommendations intended to guide universities in building and updating their graduate programs. It is not a standard, nor is it intended to be a foundational document for developing accreditation criteria to be used by accreditation agencies. GRCSE provides guidance to faculty members at educational institutions who are designing and updating graduate programs in SE, and to prospective students and their future employers to support selection of master's programs in SE to meet their particular needs" [GRCSE, Executive Summary].

MSSE: Master of Science in Systems Engineering at UTEP

Systems thinking drove the design of our program. During the initial stages of the Systems Engineering Program in 2007, an ad-hoc committee, consisting of representatives from different engineering disciplines and industries, was created. The committee was formed to address many of the startup issues presented; and an early decision was made to take a systemic approach following systems engineering practices to ensure alignment of the program with engineering educational needs and with industry needs as expressed by industry participants.

The plan consisted of four (4) different phases: Discovery, Strategic, Deployment, and the Operations phase. The different activities and objective of each of the phases is expressed below.

During the discovery phase the committee concentrated on a common understanding of the needs and importance of having a program to train engineers who would be not only technically competent but also be capable as leaders, innovators, and entrepreneurs. Goals were formed with an understanding of the currently available capabilities at UTEP and in the region, regarding: (1) Industry needs, (2) Programs Offered, (3) Financial Models, and (4) Course Inventory.

We also carried out research to understand current programs and several universities and industries were surveyed about their experience on key success factors, major challenges and roadblocks encountered during the implementation of their programs.

The main intent during the Strategic Phase was to ensure alignment with the College of Engineering (CoE) vision, strategy and objectives, in light of a comprehensive analysis of programs offered by other universities, along with their program objectives, targeted audiences, sources of funding, and advisory board considerations. The output of this phase were formal vision, strategy and objectives recommendations presented to the Dean's Office for internal approval, approval of which would allow proceeding with the processes for approval by the University of Texas system and the Texas Coordinating Board, before actual implementation of the program could begin.

The Deployment Phase included the data gathering and presentation processes needed to obtain approvals from the University of Texas System and the Texas Higher Education Coordinating Board (THECB). Necessary components of the proposal included: curricula, lines of research definition, industry support, government grants, multi-department participation, and program offerings. Several existing Systems Engineering programs at major US universities were analyzed and the committee took into consideration a 2007 reference curriculum framework for a graduate program in SE published by the International Council on Systems Engineering (INCOSE) [Jain and Verma, 2007].

In order to create and implement world-class Systems Engineering, it is necessary to create a program that gains industry acceptance and generates published peer-reviewed research. We have evolved the Institute for Manufacturing & Materials Management into the Research Institute for Manufacturing and Engineering Systems (RIMES) to research and promote the use and deployment of current and future emerging systems engineering methodologies for the life cycle management of end-to-end enterprise systems, and to provide technical assistance to Small and Medium size Enterprises (SME) as a vehicle to further engage industry and academia. RIMES has several mechanisms to apply its research expertise to enterprise challenges.

2006 DISCOVERY	2006 - 2007 STRATEGIC	2007 - 2008 DEPLOYMENT	2008 - OPERATIONS
Industry Needs; University Capabilities; Programs Offered; Financial Models; Course Inventory	College Objectives; Analysis of Options; Analysis of programs offered by other Universities; Program Objectives; Target Audience; Admission Requirements; Sources of Funding; Deployment Options; Advisory Board	Internal Trial (Spring 2007) Program Approval; Multi-Department Participation; Industry Support; Government Grants; Certificate Offering; Curricula Definition; THECB Approval; Lines of Research	Certificate; MS; Research Center; Ph.D. Definition

Figure 1: Phases in the development of the MSSE Program

The National Academy of Engineering Report on 21st Century Engineering Grand Challenges not only points out such engineering challenges but also notes the Eco-Systems nature of the challenges and thus the need to foster end-to-end Systems Thinking:

> "*. . . contemporary challenges from bio-medical devices to complex manufacturing designs to large systems of networked devices- increasingly require a systems perspective. This* ***drives a growing need to pursue collaborations with multidisciplinary teams of technical experts.*** *Important attributes for these teams include excellence in communications (with technical and public audiences), an ability to communicate using technology and an understanding of the complexities associated with a global market and social context*" [NAE, 2004].

These challenges, being multi-disciplinary, require the participation not only of specialty engineering but also of the social sciences, natural sciences, and business practices. This has been a major driver in the design and evolution of the MSSE program, which has strong links to other university departments and colleges as well as external partners who have helped build a truly multi-disciplinary Systems Engineering program.

MSSE Description

The Master of Science in Systems Engineering Program was approved by the Texas Higher Education Coordinating Board in 2009, and has been developing since that time, with the addition of courses and growth in student enrollment. The program has been guided by a drive to address student and industry needs with a full array of systems engineering courses as well as associated supporting activities, such as student internships, conferences, seminars and student organization activities.

The Master of Science in Systems Engineering (MSSE) Program holds classes Monday-Thursday from 6pm-8:50pm, for the convenience of working professionals. The MSSE Program is supported by the synergistic activities of the Research Institute for Manufacturing and Engineering Systems http://rimes.utep.edu/ and the Industrial, Manufacturing and Systems Engineering (IMSE) Department http://imse.utep.edu/. MSSE Program students organized a Student Division of the Enchantment Chapter of the International Council on Systems Engineering (INCOSE). The Student Division encourages imminent graduates to take the INCOSE Associate Systems Engineering Professional (ASEP) examination.

1, ADMISSION REQUIREMENTS

Chapter 4 of the GRCSE details the background students are expected to possess before entering a master's program.

Preparatory Knowledge: Pre-Requisites

- Math Fundamentals
  - Probability & Statistics
  - Calculus and Analytic Geometry
- Science and Engineering Fundamentals
  - Natural Science Foundations
  - Engineering Fundamentals
- General Education
  - Oral and Written Communications
  - Ethics and Professional Conduct

MSSE Admission Requirements

The entrance requirements for the MSSE Program include:

- GPA > 3.0
- Letter of Purpose
- Two recommendation letters
- Official Transcripts

For applicants with a Bachelor's degree that is not in engineering, physics, or math: 21 credit hours of junior/senior/graduate level engineering leveling courses are required before an application to the program will be considered, with 3.0 GPA or greater for these leveling courses required. Because Systems Engineering is an inter-disciplinary field, the leveling courses may be from any department or mix of departments. Example leveling courses from the IMSE Department: Industrial Systems Simulation, Design of Experiments, Engineering Economy, Production and Inventory Control, Facility Plant Layout, Safety Engineering, and Operations Research I. The most important pre-requisites are math courses that are required before enrollment in engineering courses is allowed; for example, Calculus I, Calculus II, and Statistics. Persons seeking entrance may apply as a second-degree undergraduate student or as a non-degree seeking graduate student, in order to enable registration in the leveling courses.

2, ARCHITECTURE: CROSS-COMPARISON: MAPPING MSSE TO GRCSE

Chapter 5 of the GRCSE presents curriculum architecture for structuring a SE program and a common mechanism for communicating the components of an institution's SE graduate level curriculum.

Below is a straightforward depiction of the existing MSSE architecture.

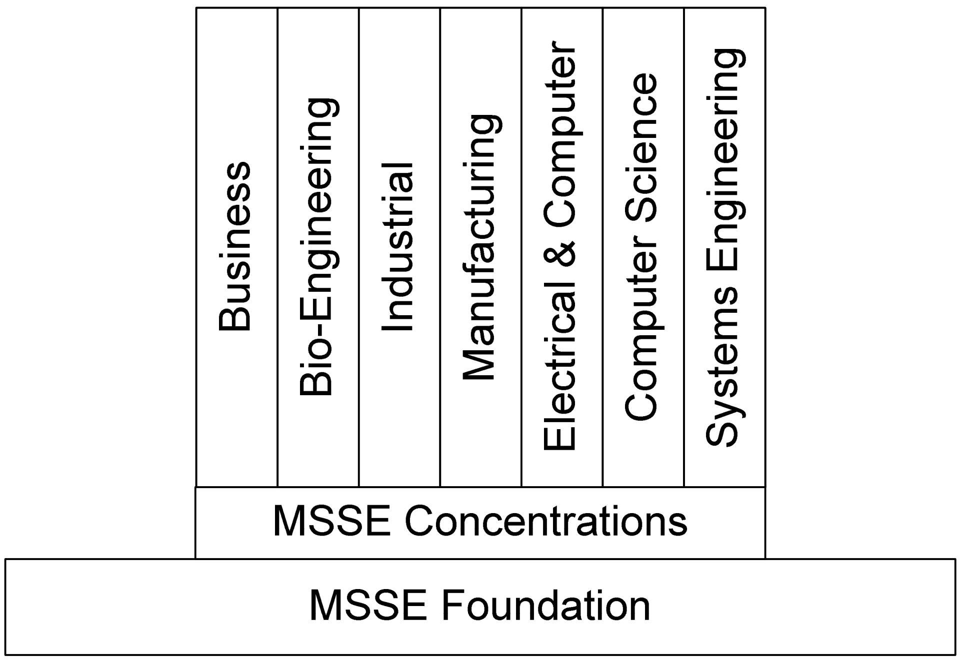

Figure 2: M.S. in Systems Engineering degree program

3, CORE

Chapter 6 of the GRCSE describes the Core Body of Knowledge (CorBoK), organized according to the curriculum architecture described in Chapter 5 and defining expected levels of achievement of learning.

MSSE Course Map

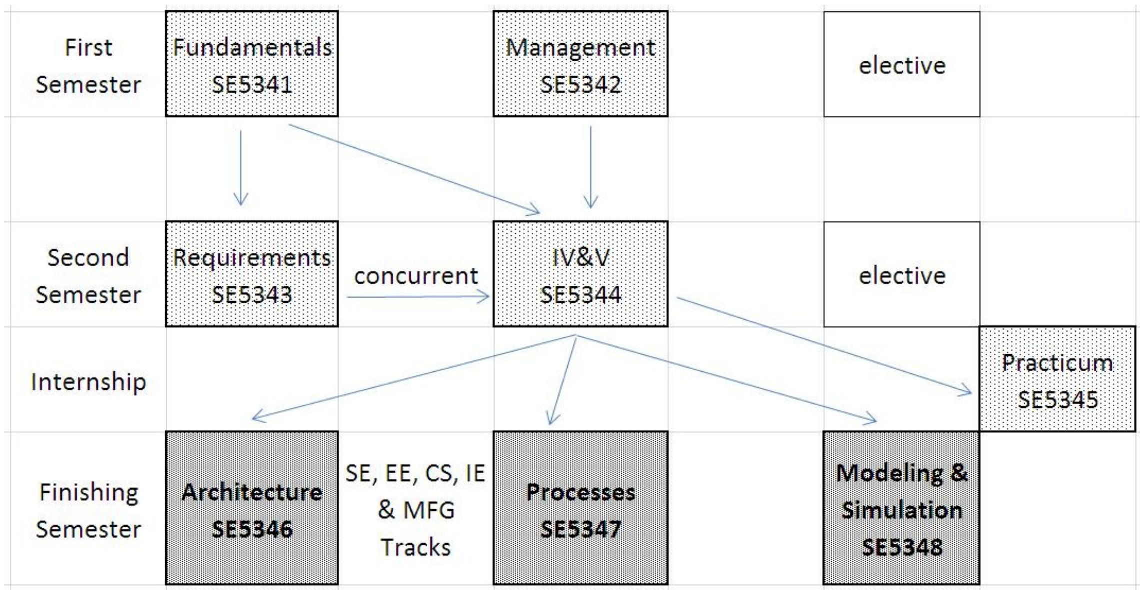

Figure 3: MSSE Course Map

GRCSE CorBoK (Core Body of Knowledge)
The GRCSE describes a generalized Core Body of Knowledge which provides the foundation for in-depth investigations and effective research.

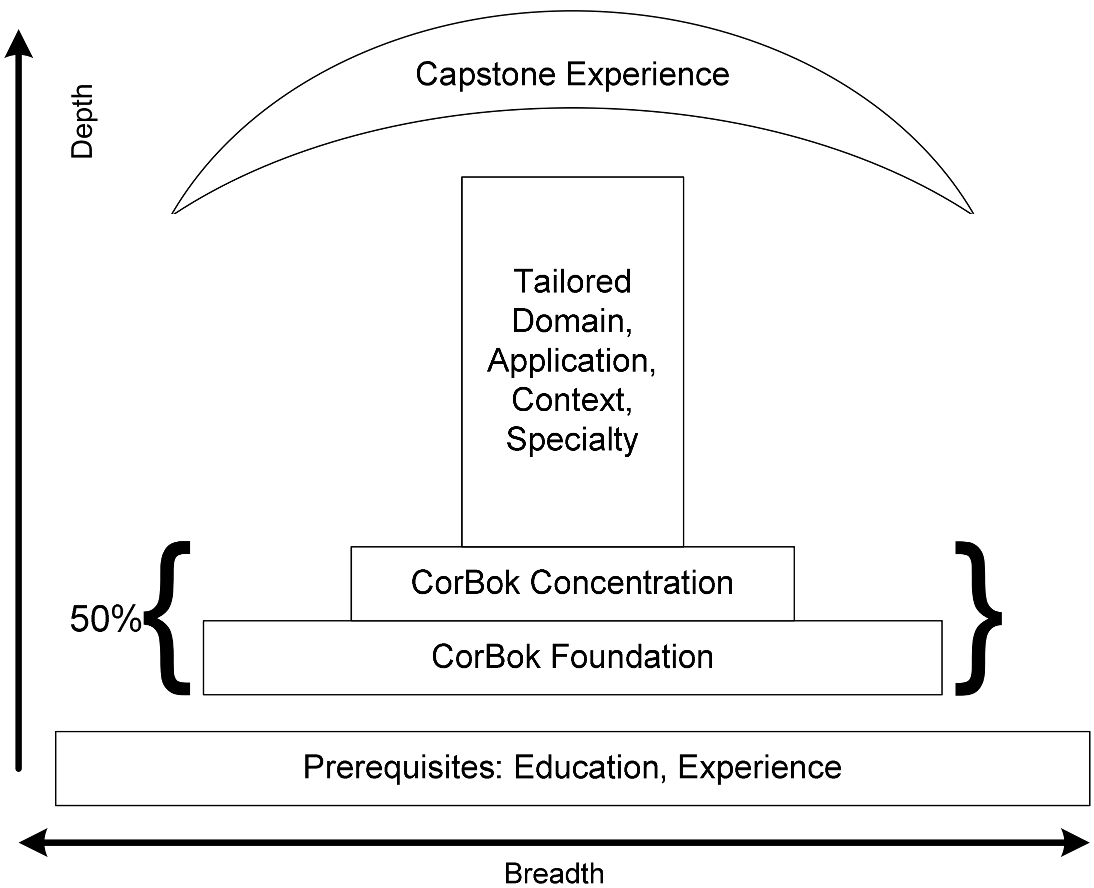

Figure 4: CorBok Organization (from BKCASE)

MSSE Course Alignment with CorBoK
The MSSE program courses align well with the CorBoK.

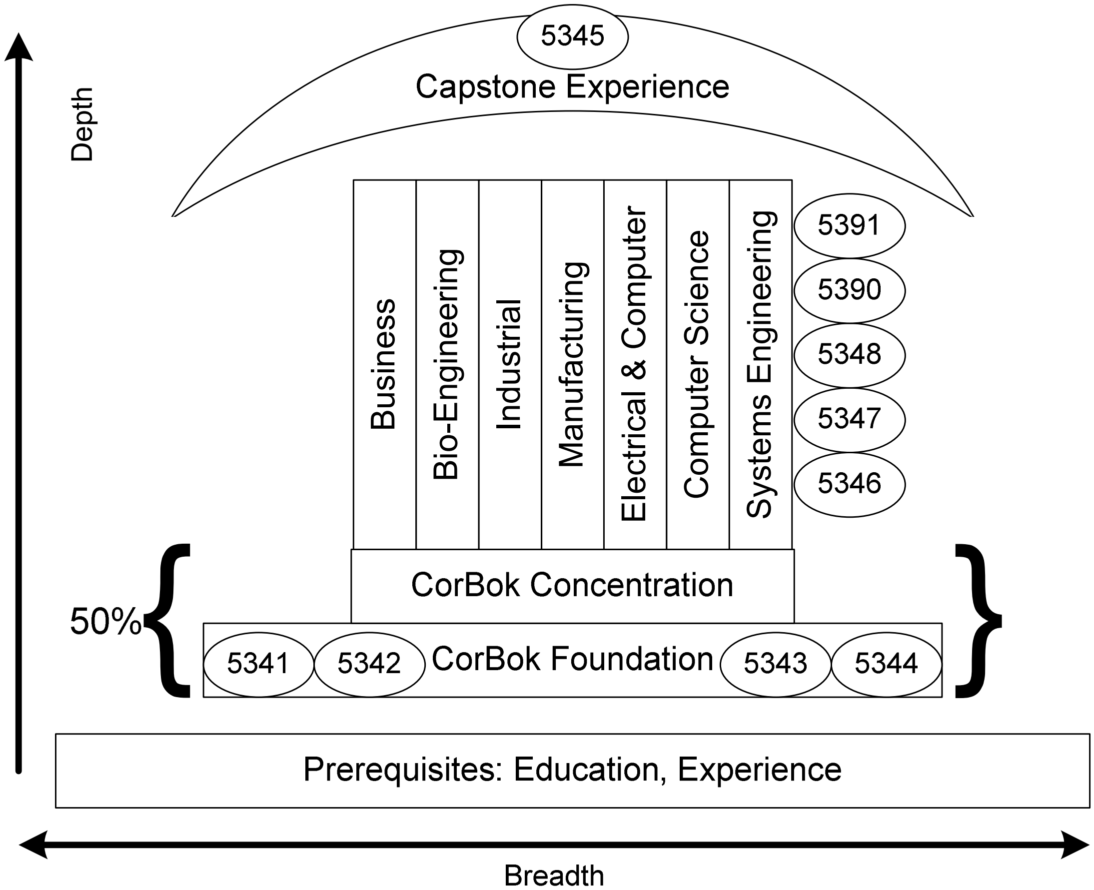

Figure 5: MSSE Program alignment with CorBok

4, CAPSTONE

Capstone experiences within the GRCSE are meant to be a full internship or project practicum that occurs after students have completed the predominant part of their engineering coursework. Capstones should provide an opportunity to drive to the full possible depth of systems engineering abilities, as well as preferable cover the full breath of the multidisciplinary educational range.

MSSE Internship Requirement for SE 5345 Project Practicum:
Each student shall participate in the SE 5345 Project Practicum capstone course after they have participated in an internship. An internship consists of fulltime systems engineering work at the worksite of an industry partner.

Students may secure an internship independently, via student-to-company applications to internships, and via RIMES facilitated applications, in which student resumes are forwarded to companies, and the companies choose candidates.

5, OBJECTIVES

Systems Engineering Educational Objectives

The program has defined five principal educational objectives which encourage our graduates to apply program outcomes to:

- assume leadership responsibilities in their field,
- innovate new products, services, and systems,
- discover new knowledge and develop new tools,
- earn professional recognition and be valued for their skills, and
- collaborate and generate benefits for their community, profession, and society.

Chapter 2 of the GRCSE describes the objectives students should attain three to five years after graduation.

SACS Educational Objectives for the MSSE Program

The Program Educational Objectives (PEOs) of the IMSE Department and MSSE Program describe the expected accomplishments of graduates during the first few years after graduation. They define our uniqueness, given our regional, bi-national focus and hence uniquely describe our program. The IMSE Department Educational Objectives are published on the IMSE Department web page as well as printed and posted in strategic locations in the IMSE Department.

Objective 1. Prepare all students for jobs in the competitive marketplace.
Objective 2. Prepare and motivate students to engage in doctoral graduate studies.

6, OUTCOMES

Systems Engineering Program Outcomes

Each of the SE courses has been developed to include the educational challenges and follow ABET requirements for the skills that go beyond technical knowledge [ABET 2009]:

- ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- ability to function on multi-disciplinary teams.
- understanding of professional and ethical responsibility.
- ability to communicate effectively.
- broad education necessary to understand the impact of solutions in a global and societal context.
- recognition of the need for, and an ability to engage in life-long learning.
- knowledge of contemporary issues.
- ability to use the techniques, skills, and modern scientific and technical tools necessary for professional practice.
- approach to core knowledge

Chapter 3 of the GRCSE states the outcomes that a student is expected to achieve immediately upon graduation.

SACS Long-Term Objectives for MSSE Graduates
These are goals for career and lifetime achievement for graduates to attain 5 to 20 years after graduation, by applying the Program Learning Outcomes.

1. IMSE Graduates will assume enterprise leadership responsibilities in Industrial, Manufacturing and Systems Engineering environments.
2. IMSE Graduates will develop innovative systems and processes for the design, development and deployment of products and services, for the benefit of society.
3. IMSE Graduates will discover new knowledge, and develop new tools for the practice of Industrial, Manufacturing and Systems Engineering.
4. IMSE Graduates will earn professional recognition and be valued for their hard analytical and creative abilities and soft skills and multi-disciplinary education and research.
5. IMSE Graduates will collaborate and generate benefits for their communities, profession, and the world.

7, ASSESSMENT RUBRICS

Chapter 8 of the GRCSE provides guidance for developing assessment rubrics to ensure that graduate programs achieve their intended outcomes.

Southern Association of Colleges and Schools (SACS)
The 2011 formulation of a Program Learning Outcomes (PLOs) Matrix for program assessment that would meet the requirements of the Southern Association of Colleges and Schools (SACS) represents the formal organization of the understanding as to how program courses and activities contribute to reaching Program Learning Objectives (PLOs), as well as to Educational Objectives. Because the MSSE Program resides in the IMSE Department, in which the only Bachelor of Science degree offered is in Industrial Engineering, the MSSE SACS Outcomes were aligned with the IE B.S. Accreditation Board for Engineering and Technology, Inc. (ABET) Outcomes.

Data gathering for the assessment of PLOs is planned to be conducted each semester, at the completion of semester courses in the Fall and Spring, when course instructors have a clear detailed as well holistic view of the progress and success in the completed semester. Data gathering remains flexible for each PLO, considering that instructor's teaching approach may change from semester to semester. For example, as to assessment of PLO D: "Students will be able to function on multi-disciplinary teams," assessment will occur in the course SE 5341 Systems Engineering Fundamentals, by either of these methods: Observation of team interactions, Project performance, Written reports, Peer feedback, or Advisor assessment. The best method of assessment will be employed, in order to accurately determine the semester-by-semester progress in terms of PLOs. A part of the SACS PLO matrix is seen below.

Program Learning Outcomes (PLO) Assessment and Review Matrix					
Program Learning Outcomes (PLO)	**Where, when, and by whom the assessment was conducted**	**Assessment tools used to assess student performance**	**Satisfactory Performance Standards**	**Outcomes of Analyses**	**Program Follow-up Decisions and Actions**
A: Students will be able to apply knowledge of mathematics, science, and engineering to solve SE problems	Yearly instructor assessment: SE 5341 Fundamentals; SE 5343 Requirements; SE 5344 IV&V; SE 5345 Project Practicum	Homework assignments, Examinations, Project performance, Written reports, GPA, Advisor assessment	High: 85% or above; Moderate – 70 to 84%; Low: 69% and below	High: Moderate Low:	Decisions: Actions:
B: Students will be able to design experiments, collect data, analyze data, and interpret results	Yearly instructor assessment: SE 5341 Fundamentals; SE 5344 IV&V; SE 5346 Architecture	Homework assignments, Examinations, Project performance, Written reports, GPA, Advisor Assessments,	High: 85% or above; Moderate – 70 to 84%; Low: 69% and below	High: Moderate Low:	Decisions: Actions:

Table 1: Program Learning Outcomes (PLOs) Assessment and Review Matrix

8, SPECIFIC NEEDS

Chapter 7 of the GRCSE includes guidance on implementation, focusing on using GRCSE as a tool for curriculum development and revision. It includes considerations for tailoring GRCSE recommendations to fit a program's specific needs in terms of stakeholder requirements and environmental constraints.

The MSSE Program's specific needs are formed by its local environment, which has informed the vision and mission of the housing institution and college of engineering. Serving residents of the locale involves providing educational access to university programs that must at the same time maintain national standards of excellence. Students from a broad range of undergraduate engineering programs are encouraged to continue their education at the graduate level within the trans-disciplinary systems engineering program. All students are supported in their need for an internship or project practicum to fulfill this program requirement.

9. MSSE STATISTICS

Over a period of four years the MSSE program has been growing steadily at a rate of 80% per year in student numbers and at 200% in industry and government funding. 100% of our students have graduated with a pre-professional experience of at least 500 hours in private industry projects and 96% of eligible students obtained job offers prior to graduating or are currently working professionals (employers include Fort Bliss, White Sands Missile Range, Lockheed Martin Aeronautics, Boeing, Raytheon, and Ysleta School District). We have enabled multidisciplinary education by engaging students from varied backgrounds including EE, IE, ME, MME, Business, and Social Science.

We have established a very strong Advisory Board to provide input on industry expectations, to guide us in the definition of a vision and mission for the programs, to review curriculum and course content, to advise on creation of projects and areas of research of interest to the industry, to help us track program progress, and to provide comparisons with national and international standards. Advisory Board members include: LMC-Aeronautics, Jacobs Engineering, Raytheon, NASA, WSMR, Sandia National Labs, Miratek, INCOSE Enchantment Chapter, and University of Arizona, URS Corporation, and L3-Com.

We have an INCOSE student chapter and have signed a credentialing agreement with INCOSE to help our students and professionals with ASEP certification.

In research, we enabled multi-disciplines by engaging EE, IE, Environmental, CE, Materials engineering, Geological Science in projects led by different industries including LMC-Aeronautics, Jacobs Engineering, GDC C4 Systems, WSMR, AFRL, LMC- Advanced Development Projects, Hamilton Sundstrand, Raytheon and others, accounting for over 45 developmental and research projects and more than 30 technical assistance projects.

CONCLUSIONS AND FUTURE RESEARCH

The successes we have had over a short period of time have shown us that to get commitment from industries for practice-based learning, the alignment of university research and developmental projects with corporate strategies is of upmost importance in order to get buy-in from executive management. Our students have faced tremendous challenges when presenting their work at the highest executive levels but at the same time they feel energized and enabled to intelligently self-direct their own learning once they return to the class environment after their Project Practicum practice.

Recent research findings on the best practices for industry-university collaboration seem to validate our relational model and point out the need to enhance our model by examining the set of best practices against our basic model premises. We still have questions about the future sustainability of the model in light of the program growth rate over the last 4 years. Can we keep providing our students with a semester-long practice with 80 or more students in the program every semester? Should we cap our enrollment if our working principles are threatened? How many companies and industries are really willing to commit to a sizeable investment to get engineering students into a practice-based curriculum? Should there be government support similar to support for medical schools? Is our model a point solution or can it be extended to all the engineering fields? These are questions that we hope to answer by cultivating the continued success of our program, including its evolution toward the proven architecture described in the GRCSE.

MSSE Future Plans

1, Thesis Option & Seminar Series
2, ASEP/CSEP INCOSE certification preparation
3, Interoperability with IE and MFG programs
4, Service & Product Systems Engineering concentration option
5, Smart-grid & Energy Systems Engineering concentration option
6, Healthcare Systems Engineering concentration option
7, Medical Center Model for stakeholder interaction
8, Competencies and Bloom's levels assessment

APPENDIX

Systems Engineering courses at UTEP

SE 5341: Systems Engineering Fundamentals & Architectures (3-0)
SE 5342: Project & Systems Engineering Management (3-0)
SE 5343: Requirements Engineering (3-0)
SE 5344: Integration, Verification & Validation (3-0)
SE 5345: Special Project Practicum in Systems Engineering (3-0)
SE 5346: Systems Architecture and Design (3-0)
SE 5347: Systems Engineering Processes*
SE 5348: Systems Modeling and Simulation (3-0)
SE 5390: Systems Engineering Special Topics
Special Topics in Systems Engineering: Advanced Topics in Complex Systems.
This course will apply Systems Engineering (SE) Methods, Processes and Tools (MPT) to current challenges in modern end-to-end Systems-of-Systems (SoS) and Complex Systems-of-Systems (CxSoS), including the design of large scale smart energy grids, healthcare delivery systems of systems, service systems enterprises, and environmentally sustainable industries.

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